HIGHWAY RESEARCH REPORT

DEVELOPMENT AND EVALUATION OF AN AUTOMATIC CUT-OFF DEVICE FOR THE EXUDATION PHASE OF THE R-VALUE TEST

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Final Report
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Mr. J. A. Legarra
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Dear Sir:

Submitted herewith is a research report titled:

THE DEVELOPMENT AND EVALUATION OF
AN AUTOMATIC CUT-OFF DEVICE
FOR THE EXUDATION PHASE
OF THE R-VALUE TEST

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Very truly yours,

JOHN L. BEATON
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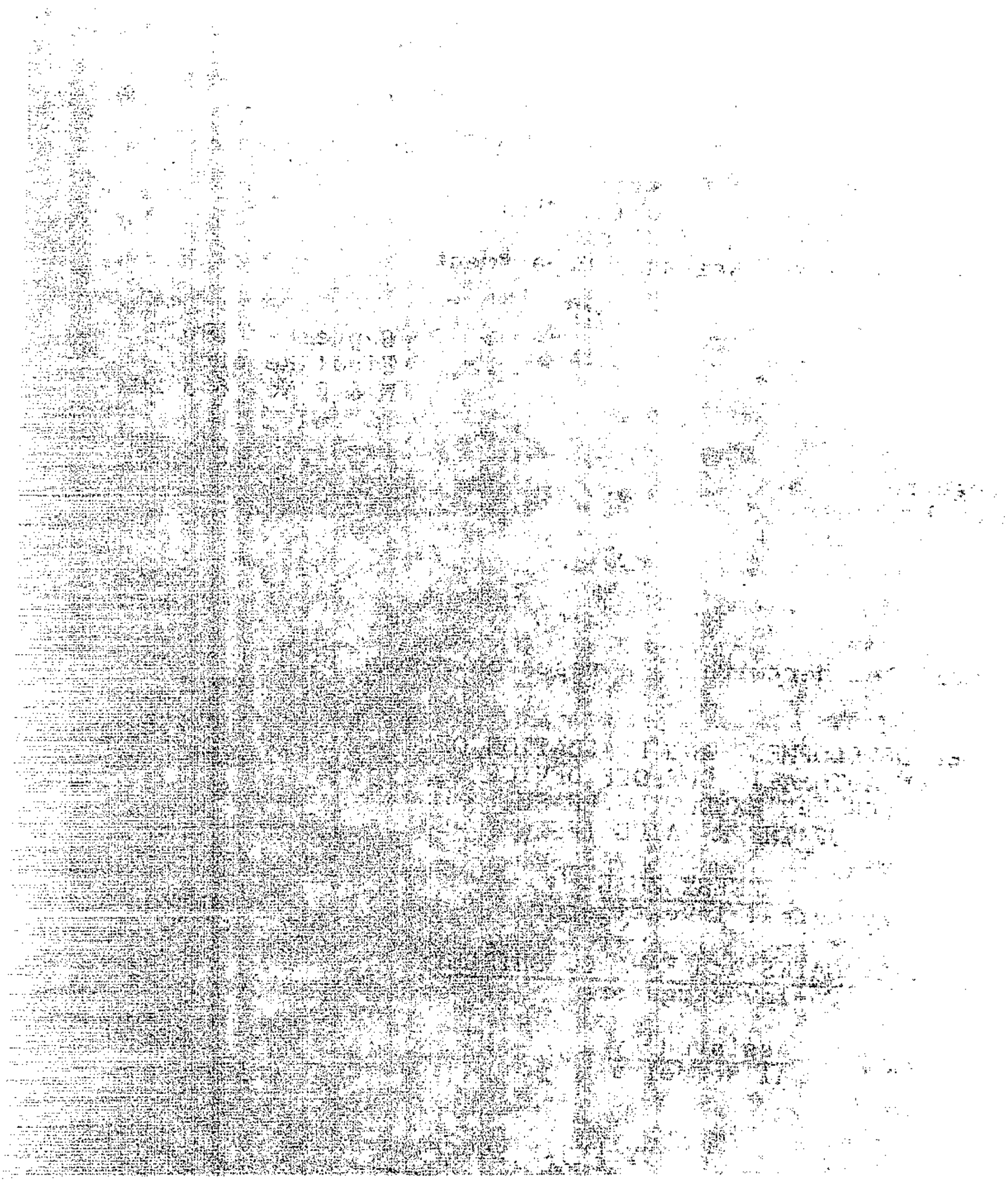

FOREWORD

The increasing cost of manpower and a continuing search for accuracy make reappraisal of test methods and equipment necessary. The frequency of such reappraisal has increased in recent years due to rapid advances in technology. The development covered by this report resulted from such a reappraisal.

This report concerns one phase in the partial automation of the Resistance or R-value test, the design of an automated exudation system.

This investigation was performed under expenditure authorization 643320 and was financed with State funds.

REFERENCE: Zube, Ernest; Gates, Clyde G.; and Shirley, Earl C., "The Development and Evaluation of an Automatic Cut-Off Device for the Exudation Phase of the R-value Test," State of California, Department of Public Works, Division of Highways, Materials and Research Department. Research Report 643320, September 1967.

ABSTRACT: The development and evaluation of an automatic device for the exudation phase of the R-value test is reported. The automatic system consists of an "exudation" plate and attendant circuitry for sensing the point at which a soil sample becomes saturated. It replaces an older device which demanded constant attendance and vigilance from the operator and replaces human judgement with measurable criteria. Future automation of this entire phase of the test is now possible since this automatic system can help control an automatic press.

Test reproducibility should be enhanced due to the use of an audible signal to notify the operator of the end of the test.

A limited statistical testing program was used to compare test results from the new and old systems and revealed no significant difference in actual exudation pressures obtained. A major advantage of the new system will be in the form of labor savings when the device is used with an automatic testing press. Circuit drawings and photographs of the prototype unit are included.

KEY WORDS: Automatic control, automation, testing, testing equipment, soils, exudation pressure, test methods, Hveem stabilometers, development, evaluation, electronic devices.

CONTENTS

INTRODUCTION

The R-value test method (1) is not only complex, but also requires considerable technique and demands an alert operator. Poor reproducibility results when all details of the test are not strictly followed.

Although considerable effort has been expended to make the test less sensitive to inexperienced operators, gains have been hampered by problems in the "exudation" phase of the test. In this portion of the test, a cylindrical soil sample, 4 inches in diameter and 2½ inches high, is subjected to a vertical load while confined in a steel mold. As the load increases, the sample consolidates and moisture previously mixed into the specimen fills the voids in the soil. When the voids are filled, the sample is saturated and moisture escapes from the bottom of the specimen through a perforated metal disc.

This exudation of moisture wets a filter paper immediately beneath the perforated disc and causes completion of an electrical circuit. A schematic representation of this procedure is shown in Figure 1. The "on" condition of the circuit is registered by judging the brightness of a neon lamp. There are six such circuits in the exudation plate beneath the filter paper. Completion of any five of these circuits shows the operator that the test is ended. The vertical load at this point is recorded in psi and is termed the "exudation pressure". Saturation is also acknowledged and the test ended when any three circuits are completed and water exudes around the periphery of the mold between the mold and the exudation plate.

The present procedure requires that an operator maintain careful watch on the periphery of the mold, judge the "on" condition of neon lamps with variable brightness, and control the rate of loading of the testing press.

In a previous minor research project, the exudation plate was modified by adding a metallic ring to detect the escape of free water around the periphery of the mold (see Figure 2). In this same project, an electronic device (see Figure 3) was built to monitor the circuits and audibly advise the operator when any of the above "end-of-test" conditions prevailed. This device was also capable of triggering a relay to halt press motion when the exudation pressure was attained. The circuitry utilized solid state components and was battery powered. The lamps were retained as visual indicators but no longer performed a function in the circuits. Since the circuits were either on or off at a specified and individually adjustable resistance, the judgment of brightness was no longer a variable. The adjustable resistances also provided means for experimental changes in electrical criteria. In many respects, the application of this device was very similar to one constructed by Contra Costa County in 1958 (2).

The specific purposes of this present research project were: To refine the previous circuit design by eliminating minor voltage variations, to eliminate the expense and variation caused by battery operation and, at the same time, ensure operator safety; to evaluate the performance of a prototype through a testing program, and to provide a schematic diagram for inclusion in bid invitations for an automatic testing press.

CONCLUSIONS

A properly calibrated automatic exudation system is compatible with the existing test method. This means that substitution of the automatic system for the current system will not result in a shift in R-value for a given soil.

When the automatic system is used with a manually controlled testing press, it is reasonable to expect that reproducibility of results will be improved by elimination of operator judgment and substitution of an automatic alarm for constant operator vigilance.

The automatic system, when used with a suitably modified (automated) press, will make possible substantial reductions in labor.

RECOMMENDATIONS

The automatic exudation system should be placed in use as a routine production tool. However, manufacture and distribution of the units should be withheld until evaluation with a totally automated testing press can be accomplished. A comprehensive recommendation and analysis may be made at that time.

An automatic press is on order and delivery should be made in early fall of this year. Evaluation can be conducted at that time under Research Authorization 633255 (Reproducibility of the R-value Test).

DISCUSSION

Design and refinement of the circuitry for the automatic cut-off device was done by the Structural Materials Section. Construction of the device was also accomplished by that section. Evaluation was performed in the R-value Unit of the Pavement Section.

Design of Automatic Cut-Off Device

Primary voltage used by this device is 110V AC.

This voltage is stepped-down to 25.2 V AC and isolated by a transformer with insulation breakdown rated at over 1,500 rms volts.

Full-wave rectification is obtained with four diodes, and the DC voltage to the moisture detection circuits is stabilized by Zener diode regulation.

Silicon controlled rectifiers (SCR) act as gates in the moisture detection circuits and their sensitivity is individually adjustable using 15-turn potentiometers. To actuate the relay or buzzer, the cumulative effect of five "on" circuits is gated by another SCR whose sensitivity is also adjustable.

A calibration circuit is included which uses high and low resistance limits to aid in setting the sensitivity of the SCR devices in the moisture detection circuits.

The schematic diagram of this unit is shown in Figure 4 and the parts list in Figure 5. A picture of the completed prototype is shown in Figure 6.

Evaluation Method

The new exudation cut-off device was evaluated by comparing it with the old light-controlled device currently in use. Soils were tested using the routine R-value procedure (1) up to and including the exudation phase of the test. Test results were compared for both old and new equipment using the analysis of variance technique (3).

The soils tested were sand and gravel, clayey silt, and clayey sandy silt. Each soil was tested at three moisture contents to provide different levels of exudation pressure. Three replicate tests were performed on each soil at each moisture level. This procedure was repeated for both exudation systems.

The testing press used in the evaluation was non-automatic. Using the old exudation equipment, the operator controlled the rate of load application, watched for exudation of free moisture, the evaluated then brightness of the neon indicating lights to determine the cut-off point for the test.

With the new equipment, the operator was required only to attend to the rate of load control.

Two points of comparison were of primary interest:

1. The characteristics and calibration of the electrical circuits in the new device must provide cut-off points showing no significant difference when compared with those arrived at using the old system. This is necessary to preclude variations in R-value between the two methods.

2. The reproducibility of the exudation pressure using the new equipment would, hopefully, be better than that of the old equipment. This would contribute to advances in testing accuracy which are highly desirable with such complex tests.

Results

Analysis of the limited data, except for one instance, (see Tables 1-3) demonstrates no significant difference in the exudation pressures as determined by the two systems.* The overall results then, would indicate that the new system could be substituted for the older system with no change in test results.

It is difficult, with this limited analysis, to make positive statements about the relative reproducibility of results with the two exudation systems. For this reason, further analysis under Research Authorization 633255 (Reproducibility of the R-value Test) is desirable to fully evaluate the performance of the new automatic system.

The fact that this study did not demonstrate a great improvement in test reproducibility with the new system, can be attributed to the experienced, vigilant operators used for the research propect.

It is assumed that operator error in routine testing occurs due to inexperience, inattention, and fatigue. These errors would certainly be reduced by using the new exudation system.

Based upon the results of this research project, a schematic diagram of the circuit was included with our specifications for an automatic testing press.

Use of the automatic exudation system with the automatic press is expected to provide substantial savings in laboratory labor costs.

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*The one exception occurs with only one soil and one moisture content out of three, and since the other variance ratios are small, it would seem that this one high variance ratio could be assigned to some chance variation. The chances are 1 in 20 that this could be the case.

REFERENCES

1. California Division of Highways, Materials and Research Department, "Test Method No. Calif. 301-E," Materials Manual Vol. I, Sacramento, California.

2. Garrison, W. A., "Improved Exudation Indicator" (Paper presented at annual meeting, Triaxial Institute for Structural Pavement Design, Klamath Falls, Oregon, March 1958)

3. Hicks, Charles R., "Fundamental Concepts in the Design of Experiments". Holt, Rinehart and Winston, Inc., N. Y., N. Y., February 1965.

TABLE 1

ANALYSIS OF VARIANCE TABLE TO DETERMINE THE EXISTENCE OF A SIGNIFICANT VARIATION IN EXUDATION PRESSURES BETWEEN THE OLD AND NEW EXUDATION SYSTEMS

Sample 66 - 3375 Sand and Gravel

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Critical Value For Ratio F.95
		9.0% Moisture			
Between Systems	200	1	200	<1	4.49
Residual	5,844	16	365		
Total	6,044	17			
		8.4% Moisture			
Between Systems	5,339	1	5,339	1.62	4.49
Residual	52,689	16	3,289		
Total	58,028	17			
		8.1% Moisture			
Between Systems	1,088	1	1,088	<1	4.49
Residual	169,112	16	10,570		
Total	170,200	17			

TABLE 2

ANALYSIS OF VARIANCE TABLE TO DETERMINE THE EXISTENCE OF A SIGNIFICANT VARIATION IN EXUDATION PRESSURES BETWEEN THE OLD AND NEW EXUDATION SYSTEMS

Sample 66 - 2978 Clayey Silt

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Critical Val[illegible] For Ratio F.95
		21.5% Moisture			
Between Systems	112	1	112	<1	4.49
Residual	14,288	16	893		
Total	14,400	17			
		19.7% Moisture			
Between Systems	5	1	5	<1	4.49
Residual	552,423	16	34,526		
Total	552,428	17			
		19.2% Moisture			
Between Systems	3,455	1	3,455	<1	4.49
Residual	1,283,695	16	80,231		
Total	1,288,150	17			

TABLE 3

ANALYSIS OF VARIANCE TABLE TO DETERMINE THE EXISTENCE OF A SIGNIFICANT VARIATION IN EXUDATION PRESSURES BETWEEN THE OLD AND NEW EXUDATION SYSTEMS

Sample 66 - 3723 Clayey Sandy Silt

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	Variance Ratio	Critical Value For Ratio $F_{.95}$
		20.4% Moisture			
Between Systems	5,689	1	5,689	8.34	4.49
Residual	10,911	16	682		
Total	16,600	17			
		19.9% Moisture			
Between Systems	22	1	22	<1	4.49
Residual	18,976	16	1,186		
Total	18,998	17			
		17.0% Moisture			
Between Systems	3,755	1	3,755	<1	4.49
Residual	192,689	16	12,043		
Total	196,444	17			

Figure 1

SCHEMATIC DIAGRAM OF EXUDATION PRESSURE DEVICE

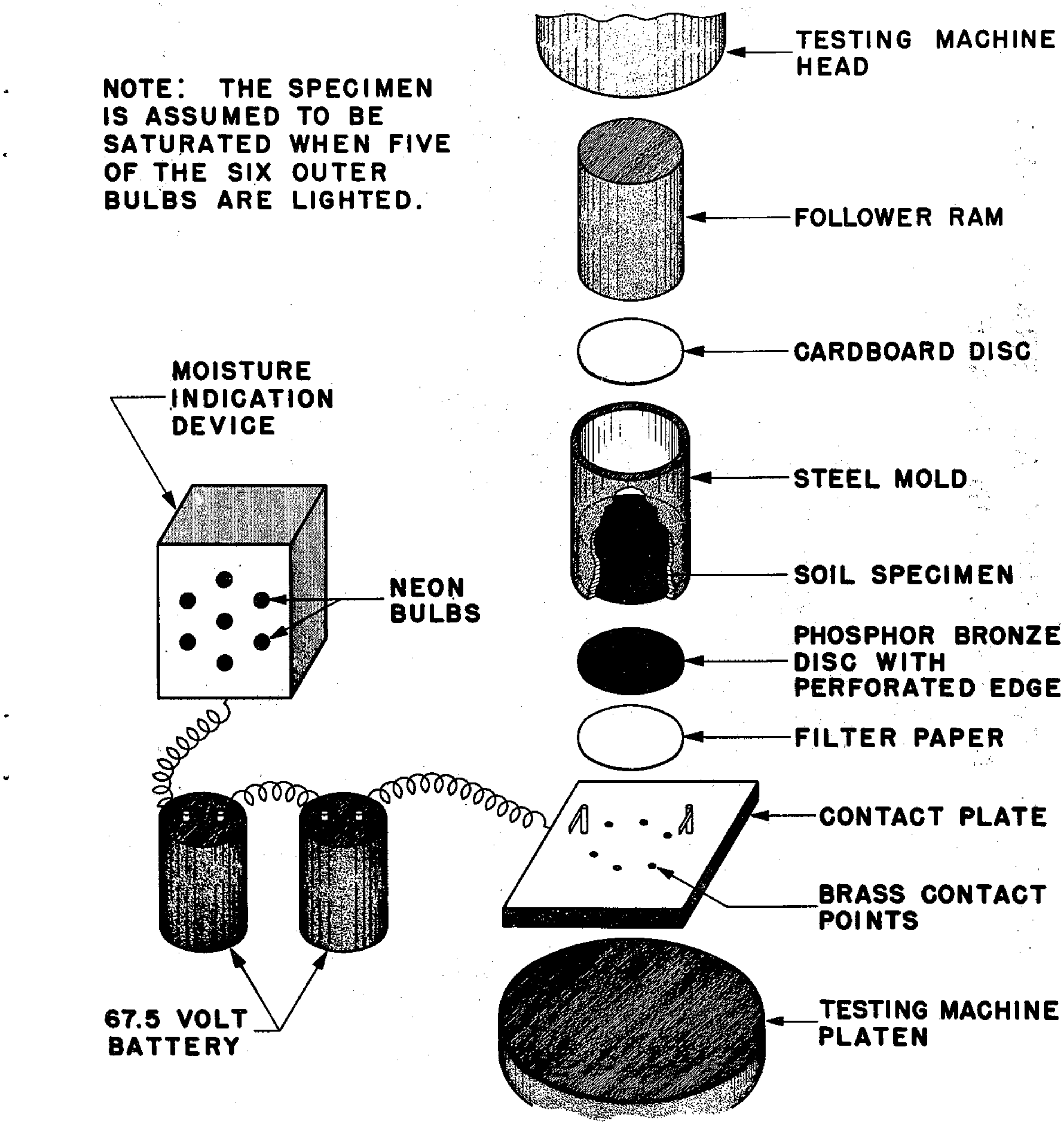
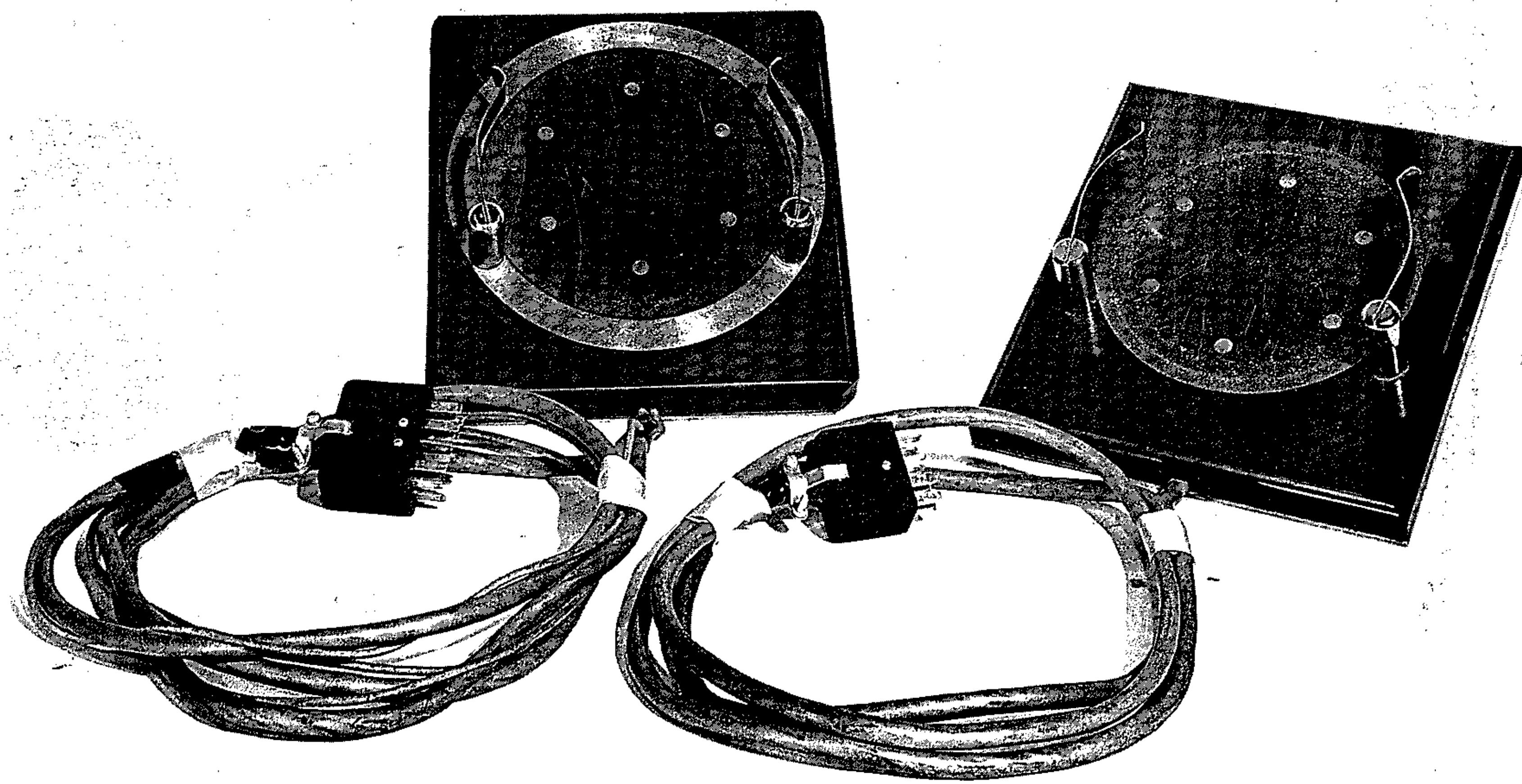


FIGURE 2

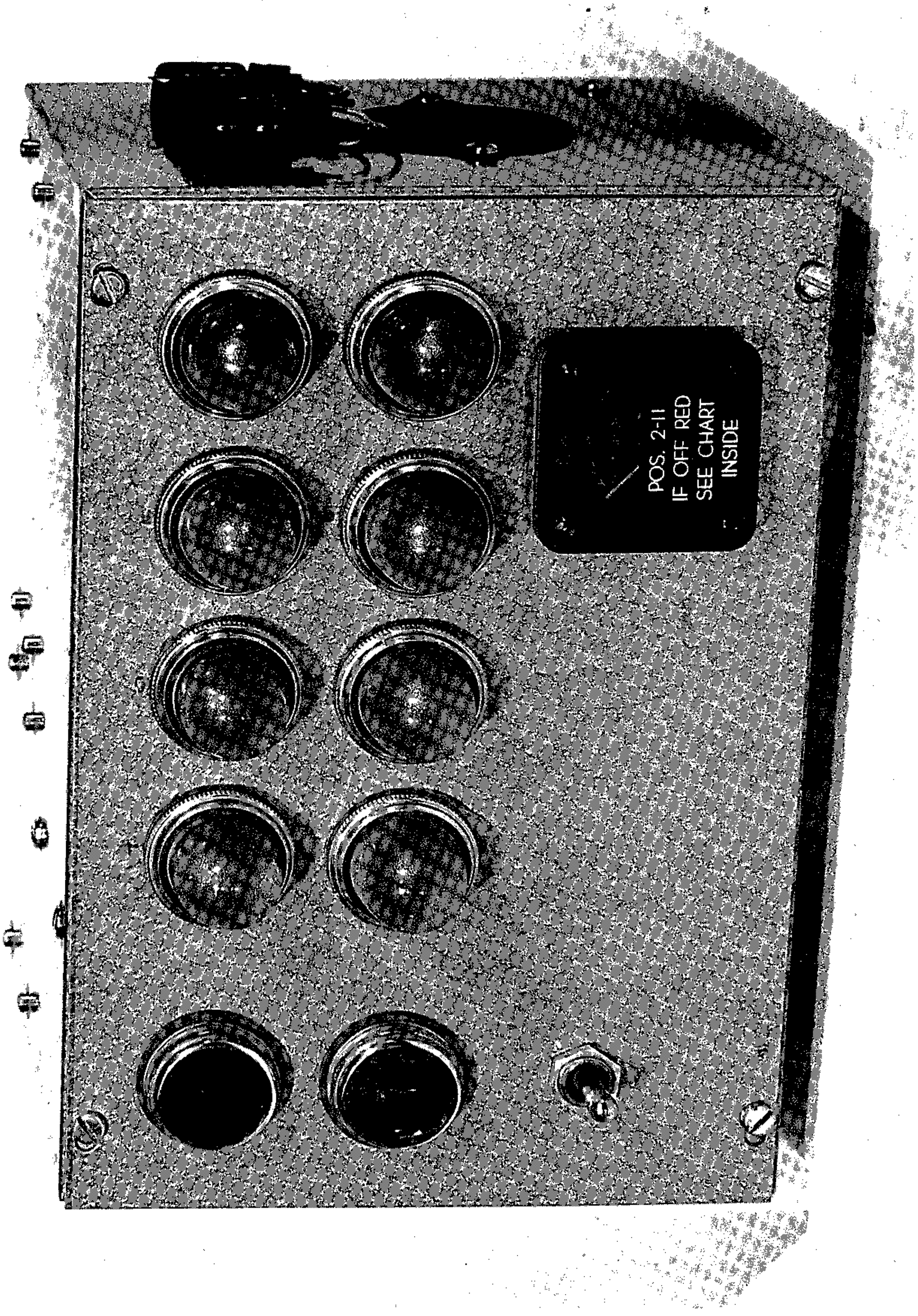
ADDITION OF PERIPHERAL BRASS RING
TO EXUDATION PLATE



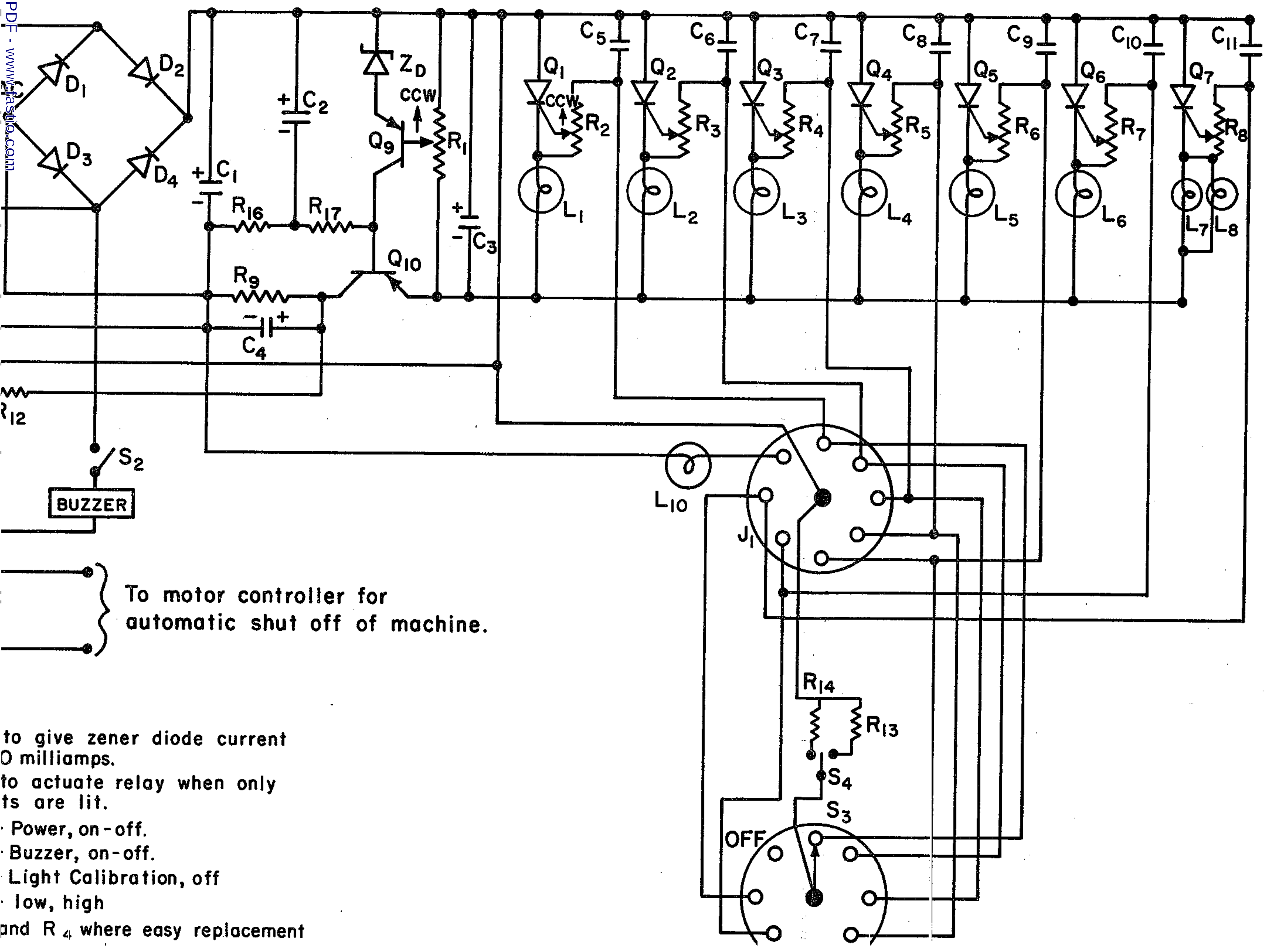
NEW STYLE PLATE

OLD STYLE PLATE

FIGURE 3



FIRST AUTOMATIC EXUDATION INDICATOR



to give zener diode current
0 milliamps.
to actuate relay when only
ts are lit.
· Power, on-off.
· Buzzer, on-off.
· Light Calibration, off
· low, high
and R_4 where easy replacement

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PARTS LIST
(for Automatic Exudation Device)

Resistors

R_1 - R_8	50K	ohms	Potentiometer (Trim Pot, Linear Taper, 15-turn)
R_9	10	"	Wirewound power resistor - 5 watts
R_{10}	750	"	" " " " "
R_{11}	50	"	Wirewound potentiometer - 3 watts
R_{12}	10K	"	1/2 watt
R_{13}	1.00M	"	± 1.0% 1/2 watt
R_{14}	0.82M	"	± 1.0% 1/2 watt
R_{15}	1.5K	"	2 watts
R_{16}-R_{17}	1K	"	1 watt

Capacitors

C_1	250	Mfd.	50 WVDC
C_2	50	"	" "
C_3	100	"	" "
C_4	1000	"	6 "
C_5-C_{11}	.0033	"	250 "

Diodes and SCR's

D_1 - D_5	Diodes rated 2A, PIV 50 volts
Q_1 - Q_7	Silicon controlled rectifier Type GE 2N2323A
Q_8	" " " " GE C106B2
Q_9	" " " " 2N1379
Q_{10}	" " " " 2N669
Z_D	1 watt zener diode 22 volts

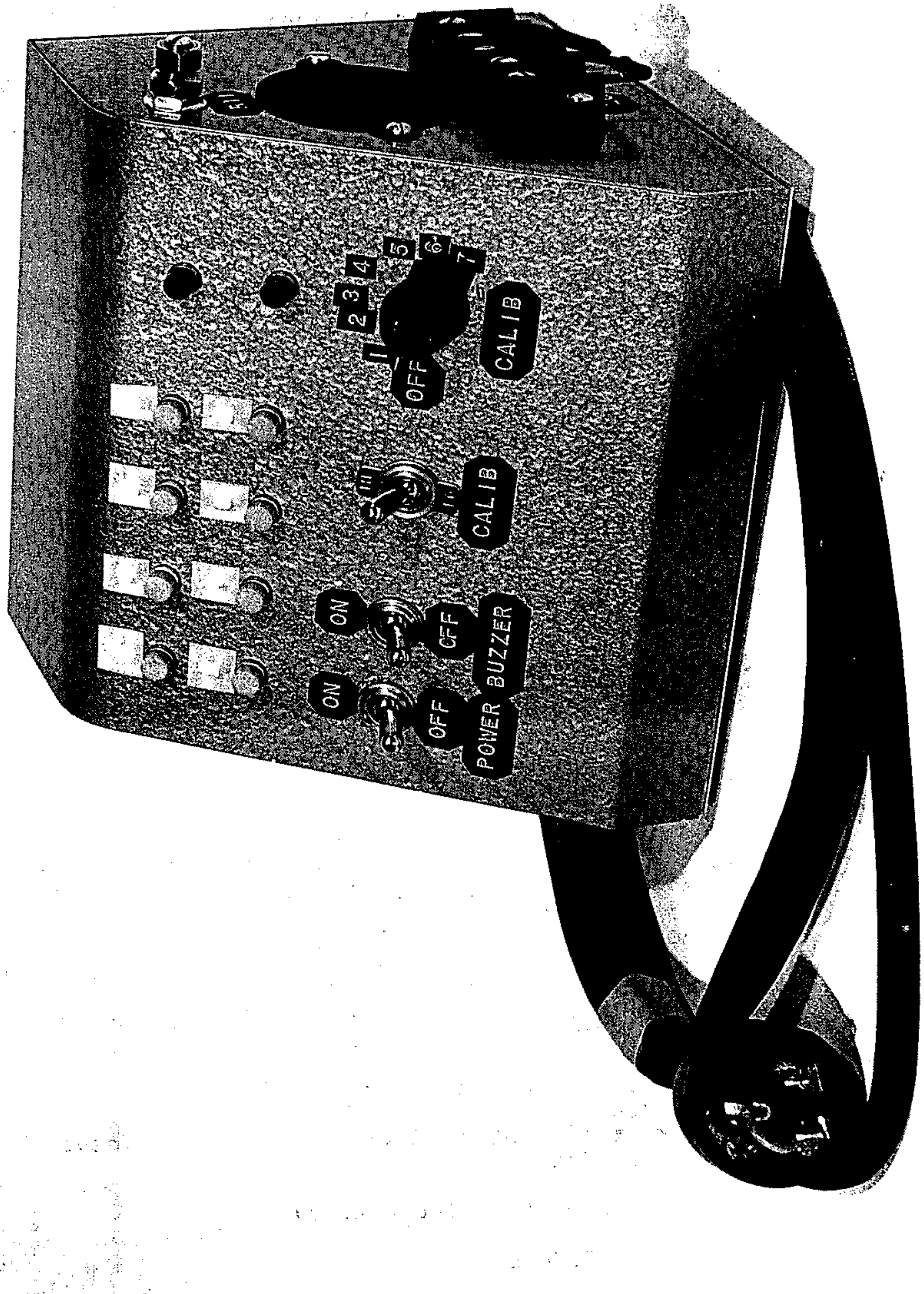
Miscellaneous

L_1 - L_{10}	Dialco lamp cartridge 28 volts @ 40 ma Type 0973 Series 507-3917 Plus Sockets
F	Fuse, 1.0 ampere
J_1	Amphenol Connector, MS 3102A-22-27S
P_1	" " MS 3102A-22-27P (to be supplied as a mating plug for J1)
K	Relay, 24VDC coil DPDT contacts - 10 amp rating
Buzzer	Type #BU - 24AC 24 volts A.C.
S_1 - S_2	SPST switch
S_3	Rotary switch, non-shorting, 8 poles
S_4	SPDT switch
T	Transformer 115 VAC to 25.2 VAC, 2a, 1500 Insul. rms volts. Triad #F-41X

Note: All parts ± 10% unless otherwise specified.

FIGURE 5

FIGURE 6



PROTOTYPE EXUDATION INDICATOR